April 1962

Report No. 0136-02 (12)

Copy No. _____

Bureau of Naval Weapons
Department of the Navy

INVESTIGATIONS OF HIGH EXPLOSIVES AT ELEVATED TEMPERATURES

FINAL REPORT

Volume II: Experimental Techniques

Prepared Under Contract NOrd 17881

ORDNANCE DIVISION

Aerojet-General CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE AND RUBBER COMPANY

AEROJET-GENERAL CORPORATION
Ordnance Division
11711 Woodruff Avenue
Downey, California

FINAL REPORT

INVESTIGATION OF

HIGH EXPLOSIVES AT ELEVATED TEMPERATURES

Volume II: Experimental Techniques

0136-02(12)FP

Contract No. NOrd 17881

Bureau of Weapons
Navy Department
Washington, D.C.

Prepared by: K. N. Kreyenhagen
J. P. Joyce

Date: 20 March 1962

Approved by: L. Zetnow, Director of Research, Ordnance Division

No. of Pages: 51

Classification: UNCLASSIFIED

G. C. Thronson, Manager
Ordnance Division

COPY NO. 27

FOREWORD

This document, Volume II of the final report submitted under Contract NOrd 17881, contains descriptions and illustrations of the test apparatus and procedures used in a study of properties of high explosives at elevated temperatures. The objectives and findings of the study are discussed in Volume I, and detailed test results are presented in Volume III.

CONTENTS

ILLUSTRATIONS

1. INTRODUCTION

When this study was initiated, it was decided to attempt to measure certain explosive properties up to the temperature where uncontrollable decomposition would occur after a few minutes of exposure. Because the quantity of explosives to be heated was relatively large in most experiments, ranging from 20 gm to 8 lb, and because there was a general lack of data regarding the behavior of explosives at these temperatures, it was necessary to devise special procedures which would minimize risk to the operators, and also minimize damage to equipment in the event of an unexpected explosion.

For all of the large-scale tests performed, therefore, apparatus was designed which permitted remote heating of the explosive, with the operator continuously monitoring and controlling the temperature. Where assembly of a special explosive-train arrangement was required after the explosive had been heated, remote-handling apparatus was designed and employed.

2. SPECIAL SAFETY PRECAUTIONS

2.1 EXPOSURE OF PERSONNEL

When performing experiments with explosives at temperatures where decomposition occurs at a significant rate, it is imperative that personnel be adequately shielded from the explosive at all times. During this study occasional unexpected violent explosions (perhaps detonations) of the explosive occurred, especially at higher temperatures. These explosions caused extensive damage to the test apparatus.

To provide adequate and convenient barricading, as well as to localize damage to the test apparatus, it was found expedient, for most of the experiments, to heat the explosive in partly enclosed test chambers consisting of 8-ft sections of reinforced concrete pipe having an outside diameter of 8 ft. One end of the pipe section was sealed. The other end was barricaded in such a way as to allow personnel access for test preparation and also to permit easy efflux of detonation or decomposition products.

2.2 ELECTRICAL HAZARDS

The explosives for most tests were heated in a Wood's metal bath, which in turn was electrically heated. It is important to observe strict grounding procedures with the apparatus employed. As an additional precaution, electrical leads into the test chamber should be disconnected when personnel are handling explosives in the chamber for preparation and assembly of explosive experiments.

2.3 RESIDUAL EXPLOSIVES

Any explosives which have been heated to the point where significant decomposition has occurred (they will usually be darkened in appearance) should be handled carefully and disposed of as soon as practical, since such residuals may be more sensitive and less stable, even after cooling, than the unheated explosive.

3. LARGE-SCALE THERMAL STABILITY TEST

The apparatus for this test was designed to measure the gas evolution from relatively large samples of explosive under constant temperature and constant pressure conditions. The Taliani Apparatus (Reference 1) can accomplish these same objectives, but it is limited to fractional-gram explosive quantities.

3.1 DESCRIPTION OF APPARATUS

Figure 1 is a schematic of the test apparatus. The explosive sample, heating bath, and remote handling apparatus are located in the enclosed test chamber. The gas-volume measuring apparatus, temperature recorder, and variable resistor for control of the heating bath are located in an adjacent laboratory building.

The explosive is in a 50 to 100-ml Pyrex glass heating container. In Figure 1, a wide-mouthed heating container which was used for tests on cylindrical samples of explosives is shown. This is a weighing bottle with a ground-glass lid seal (such as Ace Glass Company Catalogue No. 5566). These bottles were modified by adding a 1/4-in. glass-tube Y-assembly to the lid. One leg of the Y-assembly provided access for thermocouple leads, which were sealed with zinc chromate. The other leg was attached by means of a short rubber hose to 1/4-in.

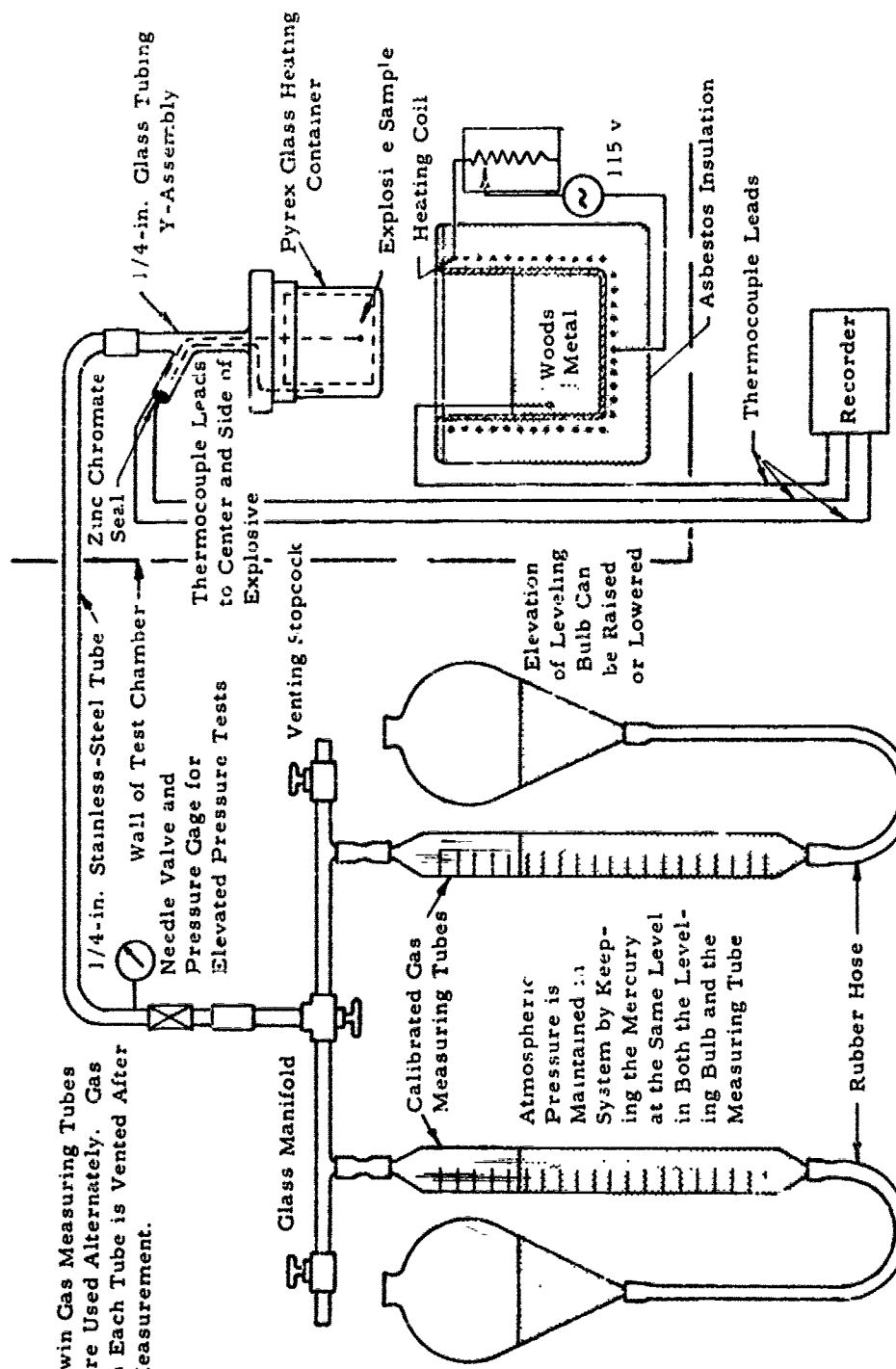


Figure 1. Schematic of Large-Scale Thermal Stability Apparatus.

stainless-steel tubing, which conveyed the gas evolved by the explosive to the measuring apparatus in the adjacent laboratory. For some tests with powdered or flaked explosive, and for the tests at elevated pressures (up to 90 psig), 50-ml Pyrex volumetric flasks (such as Braun Chemical Company Catalogue No. 29610) were used as heating containers. In this case, the neck of the flask was joined to the 1/4-in. steel tubing by a clamped rubber hose. Bare thermocouple wires were inserted directly through the hose.

The actual heating is accomplished by remotely lowering the heating container until it is completely submerged in a heating bath (or by raising the bath around the container). This bath consists of approximately 50 lb of Wood's metal in a 10-in.-dia by 8-in.-high steel pot. The pot is wrapped with a nichrome wire in series with a 1-kw variable resistor. Prior to lowering the heating container, the Wood's metal bath is heated to the approximate test temperature.

Temperature is monitored by thermocouples at three locations: in the Wood's metal bath, in the explosive sample, and immediately above the sample. The temperatures are recorded on a multichannel recorder.

The gas volume is measured in a pressure-equalizing mercury manometer. The manometer consists of a calibrated measuring tube and leveling bulb. The mercury level in the measuring tube and open leveling bulb is kept equal, thereby maintaining constant atmospheric pressure throughout the system. Twin measuring tube-leveling bulb systems are employed, both attached to a common manifold. Through appropriate stopcocks, it is thus possible to continuously measure gas volume by alternate use of the two systems.

For the elevated-pressure tests a needle valve and pressure gage are used to vent decomposition products from the stainless-steel tubing into the glass manifold.

The expected gas-evolution rate determines the capacity of the measuring tubes. For this study, either 50-ml or 1000-ml tubes were employed.

3.2 TEST PROCEDURE

The procedure for conducting the test consists of the following steps:

a. The Wood's metal bath is heated to the approximate test temperature.

b. The bulk explosive is weighed out into the heating container or the cast or pressed sample is placed in the container.

c. The heating container is clamped on the remote handling apparatus and connected to the gas-venting tube and thermocouple leads. During this step, the Wood's metal bath should be covered and electrical power leads to the bath should be disconnected.

d. The system is tested for leaks by lowering the leveling bulb several inches and observing whether a pressure differential of several inches of mercury can be maintained.

e. The heating container is remotely submerged in the Wood's metal bath. Power to the bath is adjusted as required to maintain constant test temperature.

f. The leveling bulb is lowered to maintain constant pressure in the system. The gas volume evolved is recorded at regular time intervals (It proved convenient to manually record gas volumes on the temperature recorder.)

g. To eliminate the initial thermal-expansion effect when the heating container is submerged in the Wood's metal bath, the gas volume measured during the first 5 min of the test is disregarded in reducing the data.

3.3 ACCURACY

The apparatus described was designed for measuring gas evolution from relatively large masses of explosive at relatively high temperatures. Using the 50-ml measuring tube, gas-evolution rates down to about 1.0 ml/hr could be measured (corresponding to 0.02 ml/hr/gm for a 50-gm sample).

The principal source of error in using the apparatus consists in the maintenance of desired temperatures. A skilled operator can control the temperature to within $\pm$ 5°F of the desired level. The importance of good control is evidenced by the fact that a systematic error of +10°C in the temperature throughout a test would result in increasing the decomposition rate by about 100%.

Small temperature gradients can exist between the bath and the center of the explosive, especially for nonmelting explosives. These gradients,

however, were not more than 2 or 3°F except during the first few minutes of the test and during periods just prior to uncontrollable decomposition of the explosive.

This apparatus measures only the gas transmitted through several feet of stainless-steel tubing. Some lower-vapor-pressure fractions of the decomposition products condense in the tubing

4. SHOCK SENSITIVITY TEST

This test was designed to measure the sensitivity to initiation by shock of explosives at various elevated temperatures. The general shock sensitivity test (see Reference 2 for example) consists of a donor charge initiated by a standard detonator, and the acceptor charge which may or may not react because of the shock received from the donor.

Two arrangements are possible for changing the intensity of the shock to which the acceptor is subjected. In the "minimum-primer" method, the energy of the donor is varied, either by changing its mass or by varying its explosive composition. Results are expressed in terms of the minimum primer needed for initiation of the acceptor. This method requires a supply of donors finely graded according to energy. The alternate method is the "gap" or "booster-attenuation" test. In this case, a standard donor (or booster) is separated from the acceptor charge by varying thicknesses of attenuator. The booster-attenuation test was chosen for this study because of the ease with which attenuator thickness may be varied.

4.1 DESCRIPTION OF TEST SETUP

Figure 2 is a schematic of the test apparatus showing the explosive being heated. The heating bath was mounted on the cantilevered end of a sliding carriage so that it could be inserted into the test chamber for heating and withdrawn behind the barricade during the donor firing. The remote-assembly derrick permitted personnel to raise and lower the explosive as required during the test.

Figure 3 identifies the test components. The attenuator consisted of aluminum discs 0.051-in. thick and 2.375-in. in diameter. Aluminum was chosen because its shock-propagation properties are relatively insensitive to temperature in the range of interest. The 100-lb weight

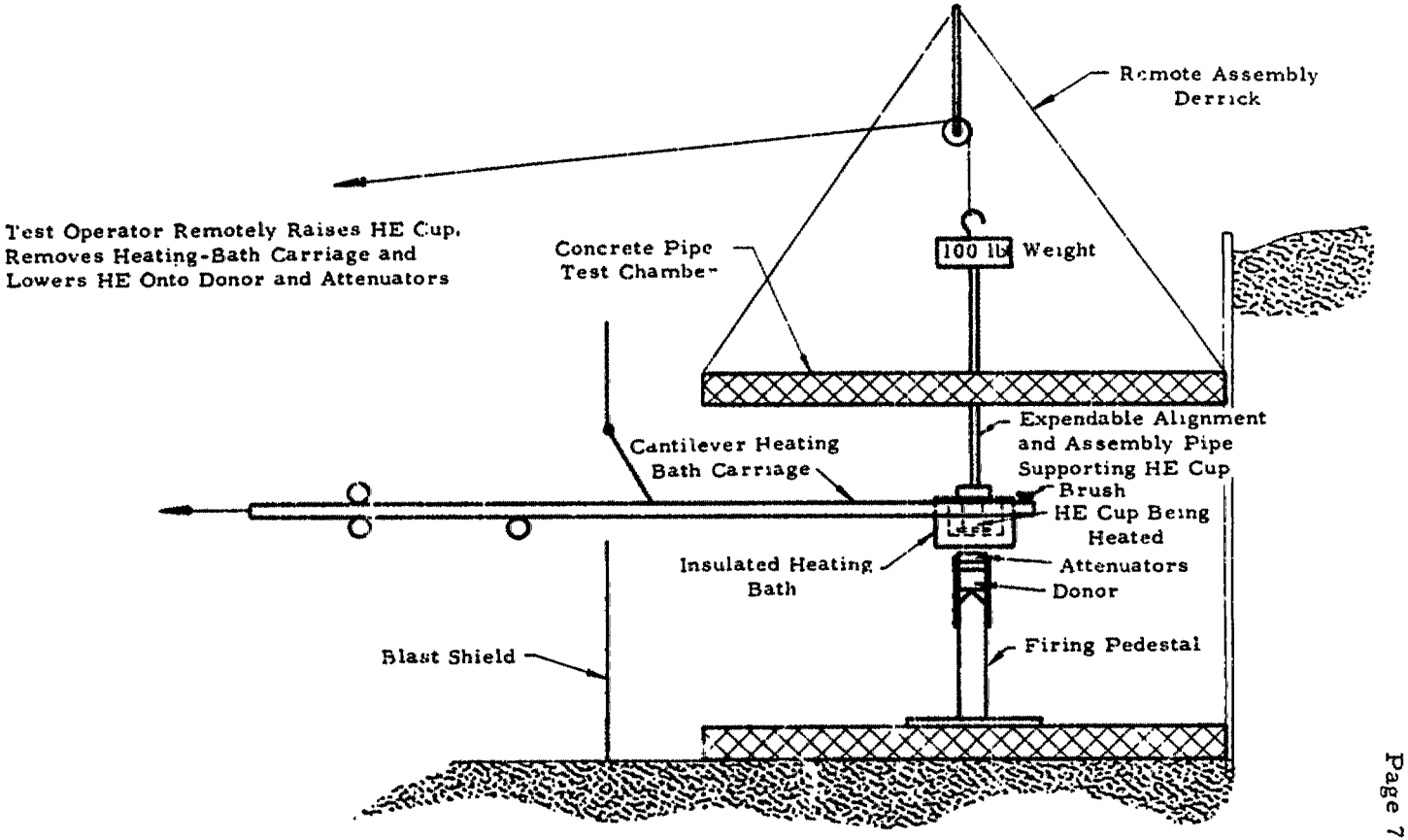


Figure 2. Shock-Sensitivity Test Heating and Remote Assembly Arrangement.

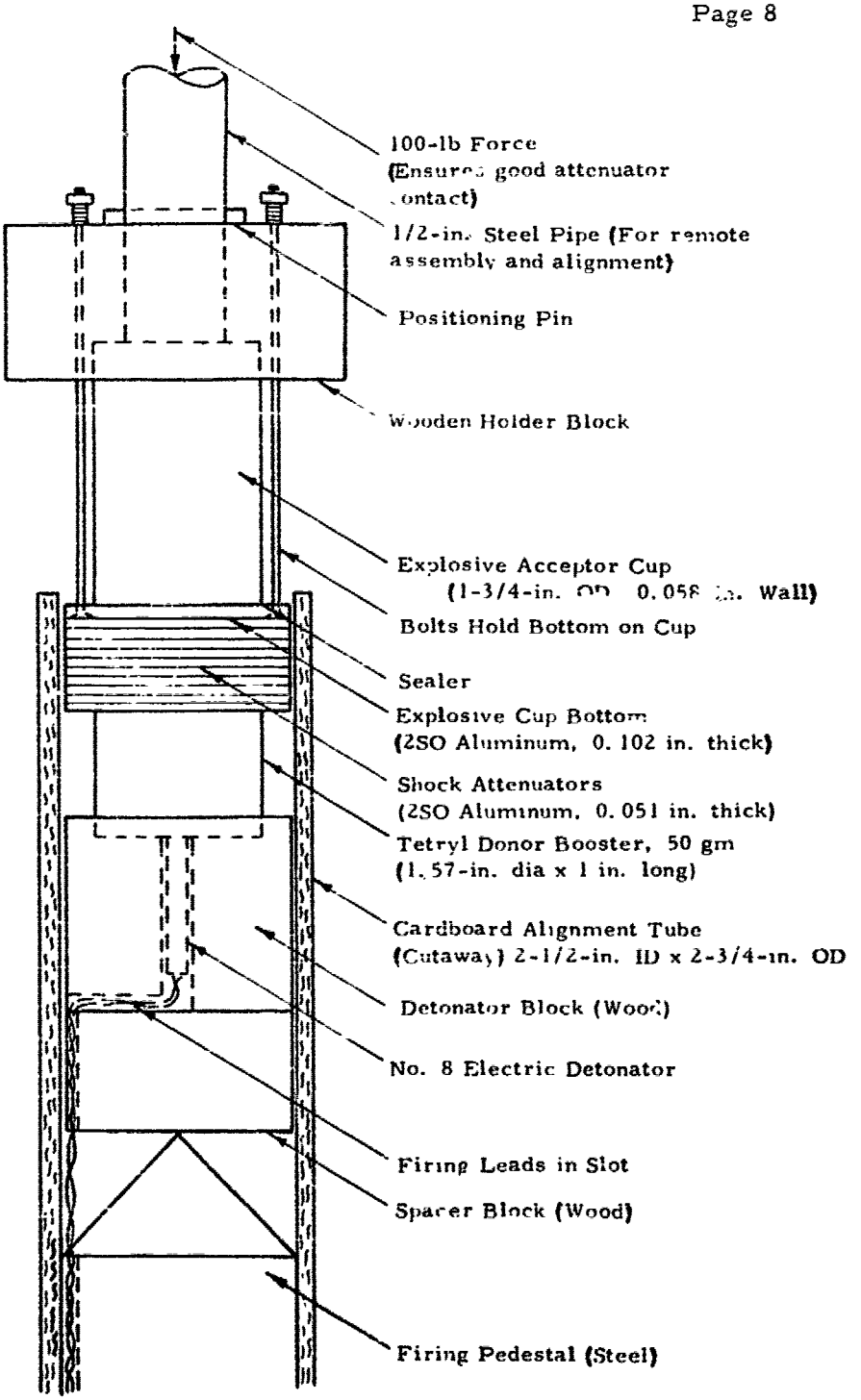


Figure 3. Shock-Sensitivity Test Setup.

shown in Figure 2 serves to press the components together, assuring solid contact at the critical interfaces between components in the shock path from donor to acceptor charges. The explosive (acceptor) cup contains 80 gm of the explosive under study. Solid explosive cylinders used in some tests fit into the cups with sliding contact at the walls.

Figure 4 is a photograph of the test arena. Twin setups were used to expedite testing. Test chambers were 8-ft.-long sections of reinforced concrete culvert pipe with an inside diameter of 81 in. Half-in.-thick steel was used for barricading. Figure 5 shows the remote-assembly derrick on top of a test chamber.

Figure 6 shows the inside of the firing chamber prior to assembly of the charge. Figure 7 shows this same view after the test components have been prepared for firing. The detonator, donor, and attenuator are all held in a cardboard tube which slides over the firing pedestal. Attached to the alignment and assembly pipe is the cup holding the explosive test sample (acceptor).

In Figure 8, the heating pot has been brought into the firing chamber, and the explosive cup has been inserted into the Wood's metal bath. This bath, similar to that described in Section 3.1 was heated electrically. The bath and explosive temperatures were monitored by thermocouples. After sufficient time for the test explosive to reach the desired temperature (30 to 45 min), the explosive cup was raised out of the Wood's metal, the heating-bath carriage was retracted from the firing chamber, the explosive cup was lowered against the attenuators (Figure 9) and the donor charge was fired. These operations were accomplished in less than 30 sec during which there was no measureable drop in the temperature of the explosive. To assure that no Wood's metal adhered to the bottom of the explosive cup to impede passage of the shock wave, a brush was installed on the heating-bath carriage to sweep the bottom of the cup clean as the carriage was withdrawn.

Whether a detonation of the explosive sample occurred following the firing of the donor was determined by examining the damage sustained by the end of the steel pipe which supported the sample cup from above. Detonation invariably caused gross evidence of plastic flow and fracture in the pipe end. This normally took the form of flanging as shown in Figure 10. If the explosive failed to detonate (even though it burned rapidly) no permanent deformation of the pipe occurred. This criterion, which may appear rather tenuous, actually yielded sharply defined data.

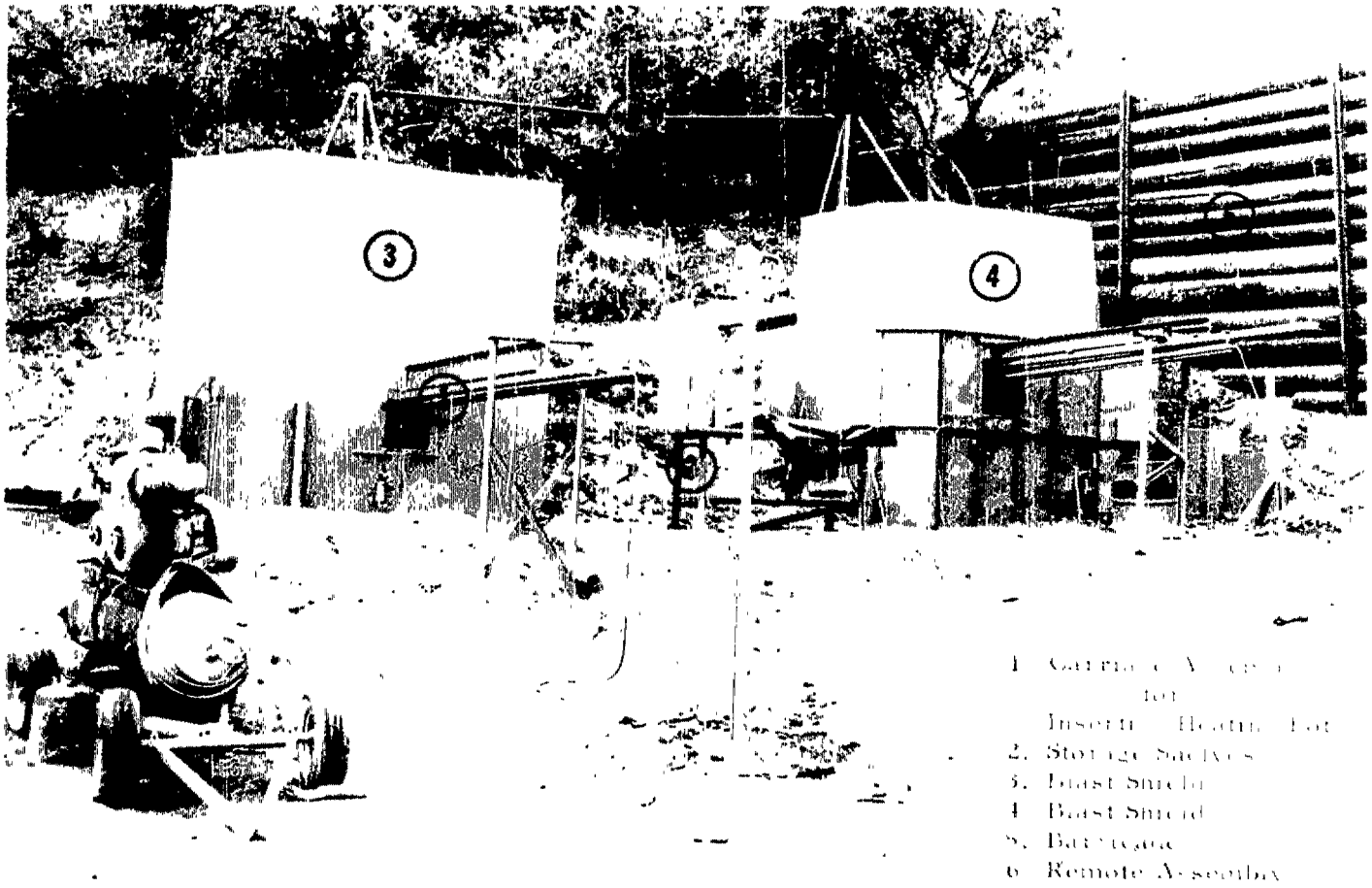


Figure 4. Arena for Shock-Sensitivity Tests.

Figure 5. Remote Assembly Derrick.

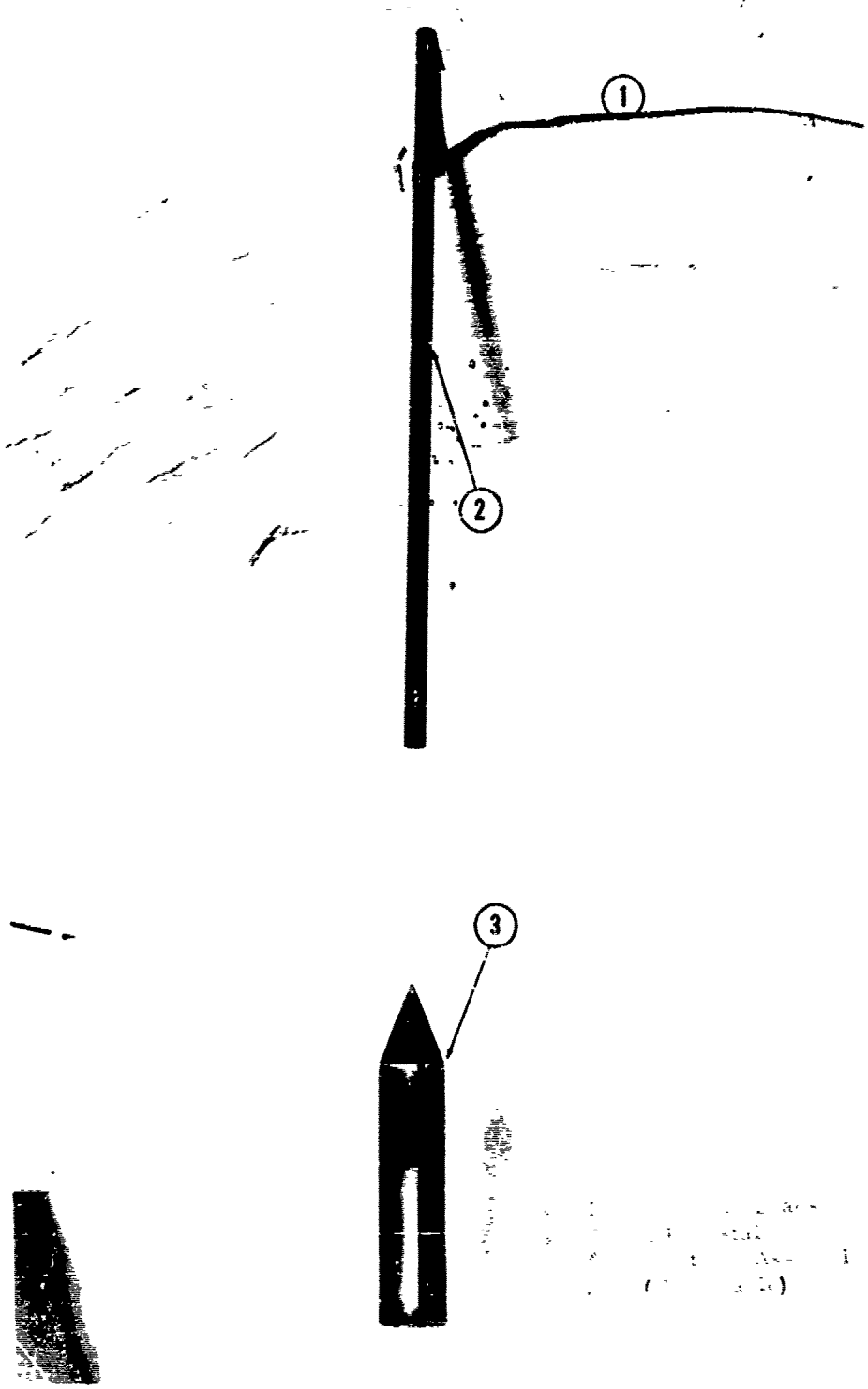


Figure 6. Firing Chamber Before Setting up Test.

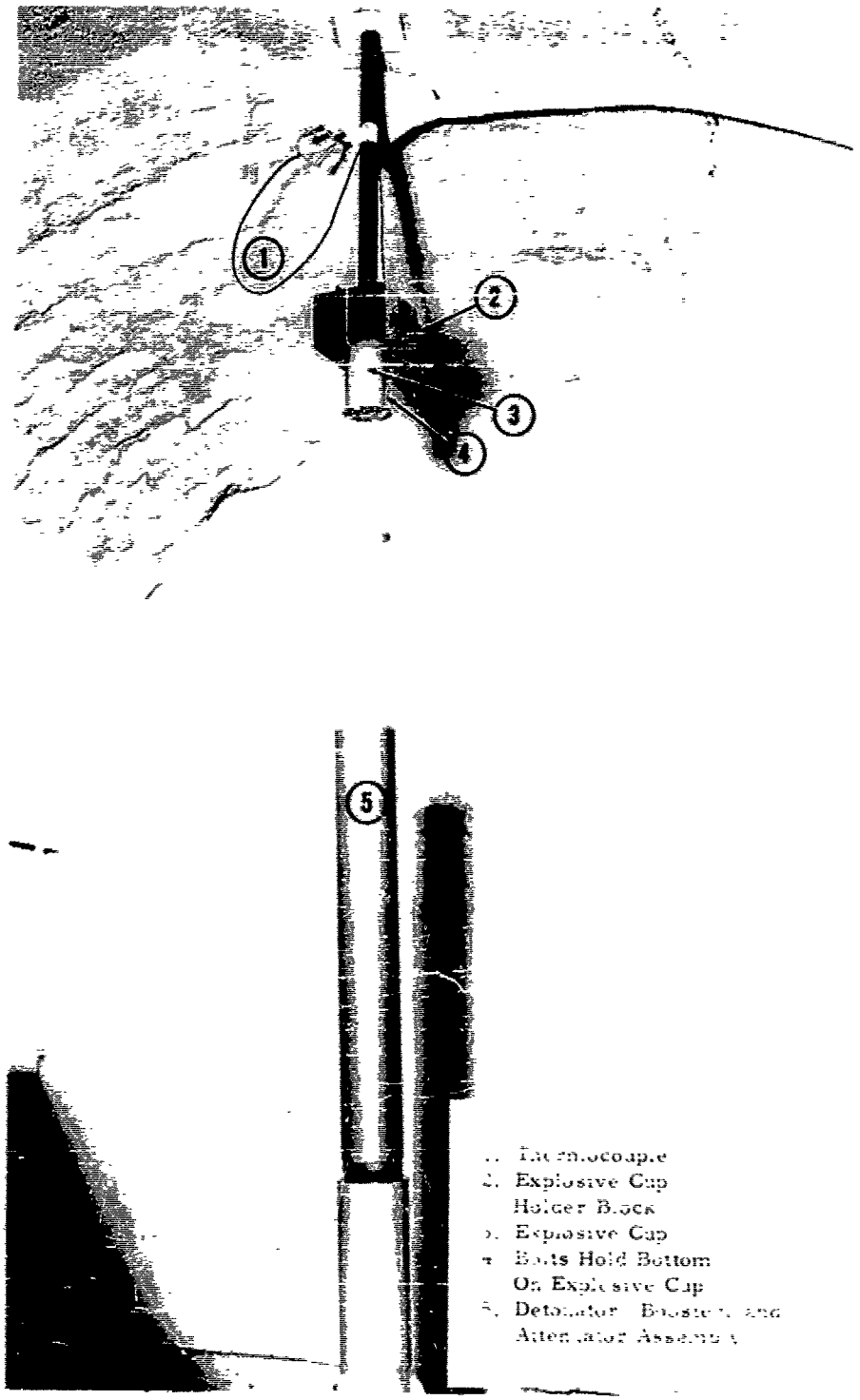


Figure 7. Assembled Test Setup Prior to Heating.

Figure 8. Heating the Explosive Sample.

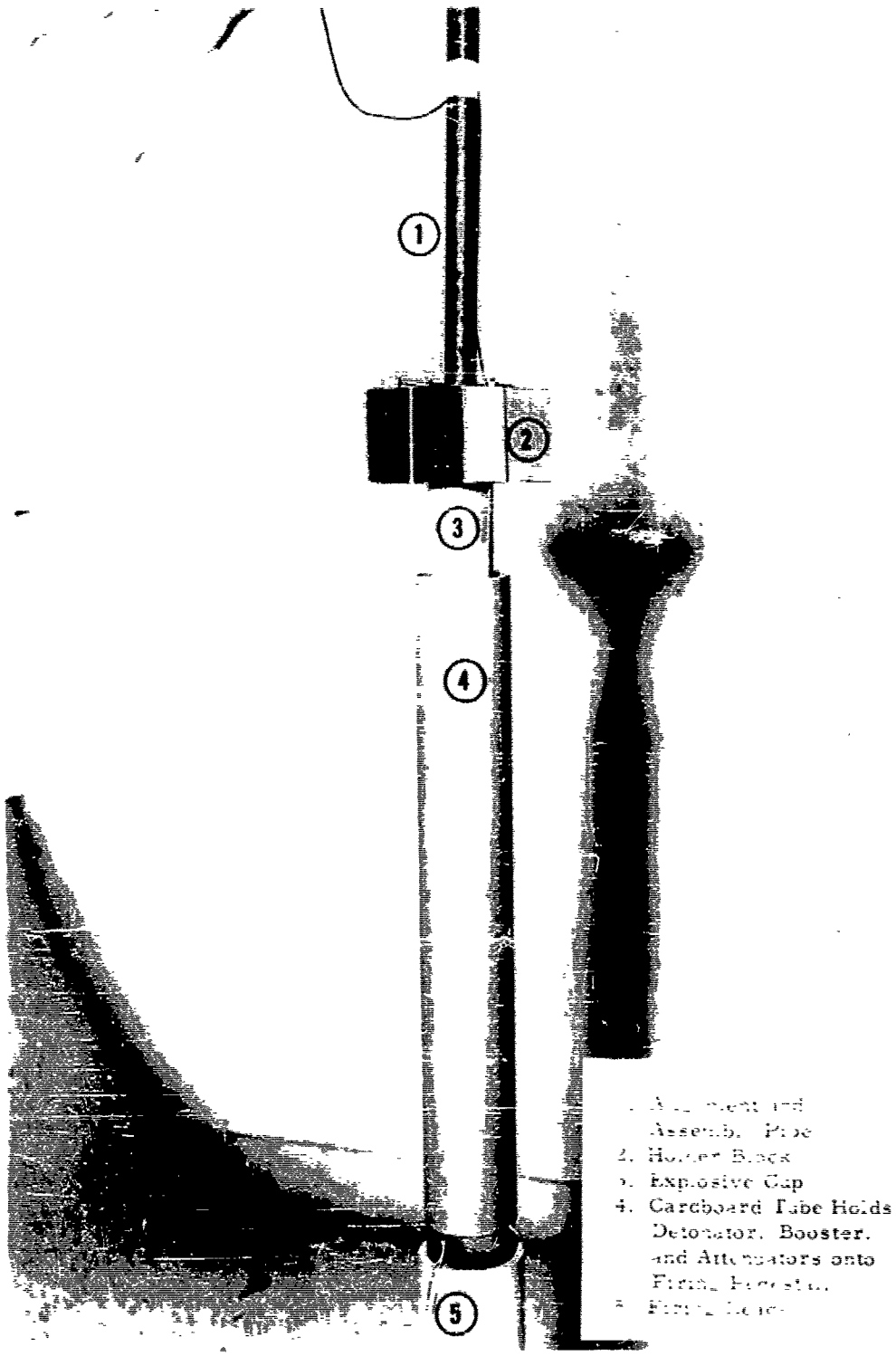
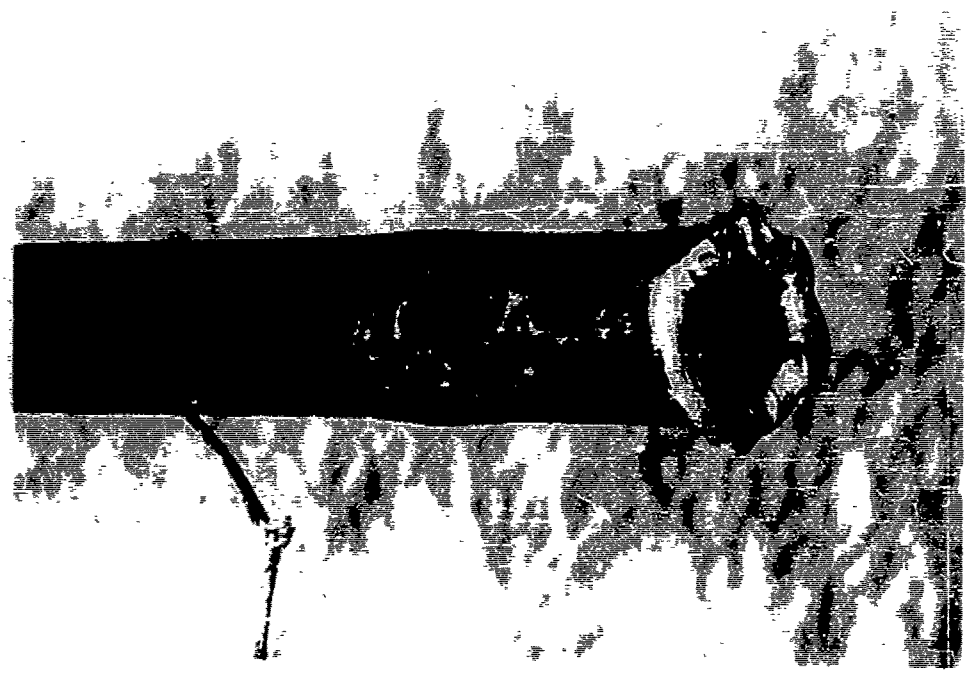


Figure 9. Test Setup Ready for Firing.

Nondetonation



Detonation

Figure 10. Damage to Assembly and Alignment Pipe During Shock-Sensitivity Tests

4.2 DETERMINATION OF 50% POINT

The test procedure is a modification of the Bruceton "up-and-down" technique used to determine attenuator thickness where the probability of detonation is 50% (Reference 3).

The minimum attenuator thickness was 0.102 in. (the thickness of the bottom of the explosive cup). If no previous data is available, the first test is conducted with the donor and acceptor separated only by the 0.102-in. cup bottom. The following detailed procedure, quoted from Reference 5, was used in this program:

"If no detonation results on the first test at zero gap, three more tests are made. Depending on these results, the testing is either concluded or additional tests are made at a four-card gap, as shown in Table 1, since the probability of obtaining these results is so low that experimental error is indicated. In these cases, therefore, the test procedure should be started anew at zero gap.

"If detonation occurs at zero on the first test, the next test is made at eight cards. Thereafter, the number of cards is doubled with each additional test until the sample gives a negative result (does not detonate). Each successive shot is then made halfway between the closest go and no-go card values. This procedure is continued until a positive and negative test have been obtained which differ by only one card. Let N = the number of cards corresponding to this positive test and N + 1 = the number of cards corresponding to this negative test.

"A basic test pattern consisting of four tests is established by making one additional shot at both N and N + 1 cards. The four possible results are shown in Table 2. If Patterns I or II are obtained, no further testing is required to establish the 50% point, and the results are as shown. If Patterns III or IV are obtained, two supplementary shots are needed at a particular card value to determine the 50% point. (One of these may already have been made in the previous sequence.) These supplementary tests and the corresponding values of the 50% point are given in the table.

Table 1.† Determination of 50% Point
(After No Detonation on First Test at Zero Gap).

... = no tests needed
\+ = detonation
\- = no detonation

Test Result--Number of Cards*		50% Point (Cards)
0	4	
----	...	<0
---+	...	<0
--++	...	0
-+++	----	1.5
	---+	2
	--++	3
	-+++	Unassigned**
	++++	Unassigned**

† From Reference 5

* Order of results is immaterial

** Repeat procedure anew, starting at zero gap

Table 2.† Determination of 50% Point for Various Test Configurations.
(After Detonation on First Test at Zero Gap)

N = an integer
\+ = detonation
\- = no detonation
. . . = no tests needed

Basic Test Pattern*			Supplementary Tests Required to Establish 50% Point	Results of Supplementary Tests*		
	Number of Cards			Number of Cards		
Designation	N	N+1		N-1	N+2	50% Point
I.	++	--	None	. . .	. . .	N + 1/2
II.	+-	-+	None	. . .	. . .	N + 1/2
III.	+-	--	Two tests at N-1	--	. . .	N - 1
				++	. . .	N
				-+	. . .	N - 1/2
IV.	++	-+	Two tests at N+2	. . .	--	N + 1
				. . .	++	N + 2
				. . .	-+	N + 1-1/2

† From Reference 5.
* For a particular number of cards, the order in which the results are obtained is immaterial.

Table 3. Sample Determination of 50% Point.

a. 50% Point = 10 Cards

Step	No. of Cards	Symbol in Table 1		Result of Test
1	0		+	
2	8		+	
3	16		-	
4	12		-	
5	10	N	+	
6	11	N + 1	-	Basic Test Con-
7	10	N	-	figuration
8	11	N + 1	-	
9	9	N - 1	+	
10	9	N - 1	+	Supplementary Tests

b. 50% Point = 11.5 Cards

1	0		+	
2	8		+	
3	16		-	
4	12	N + 2	-	Supplementary Test
5	10	N	+	
6	11	N + 1	-	Basic Test Con-
7	10	N	+	figuration
8	11	N + 1	+	
9	12	N + 2	+	Supplementary Test

* From Reference 5.

"Two sample test procedures are given in Table 3. In Example A two supplementary tests are necessary after the basic test configuration is established. In Example B one supplementary test is made before and one after the basic test configuration is obtained."

Using the procedure just described, it was found that from 14 to 20 tests were required to determine the 50% point.

A four-test procedure for rechecking the 50% point was also employed during the program. If N was the 50% point previously determined, two firings were made at both N +2 and N - 2 attenuators. If both tests at N +2 produced no detonation and both tests at N - 2 did produce a detonation, the recheck was considered to validate the original 50% point Otherwise, the entire procedure was performed again.

4.3 ACCURACY

A plot of explosive reaction vs intensity of the initiating mechanism should produce a sigma distribution, with the center of this distribution being taken as the 50% point, or the point at which the probability of detonation is 0.5.

When uncontrolled factors enter the testing procedure, the spread of the distribution may increase, and the number of tests required to accurately determine the 50% point will also increase. Such factors might include the temperature, the degree of confinement, and the presence of gas bubbles in the explosive.

During tests with this procedure, temperature control is maintained with an accuracy of $\pm 5^{o}$ by means of the variable resistor in the heating circuit. Except at relatively high temperatures(those where the rate of gas evolution is significantly changed by small errors in temperature) the effect of temperature changes of $5^{o}F$ upon shock sensitivity has proved to be undetectable. Hence, this is not considered an important source of error.

Confinement was constant throughout all of the experiments. The explosive was confined in a 1.644-in.-ID aluminum cup with 0.058-in-thick walls. Upon melting, the castable explosives were in direct contact with the walls. Pressed explosive cylinders were in sliding contact with the walls at room temperature, and were probably in firm contact at elevated temperatures.

Considerable variation in the results of such experiments may be caused by the presence of gas bubbles in the decomposing explosive at higher temperatures.

Under these conditions the explosive gives the appearance of boiling, with the bubbles random in size and location. Since such bubbles are potential sources of initiation during shock compression, their random nature will introduce a wide dispersion in sensitivity data at higher temperatures.

The shock-attenuation properties of the stack of attenuating discs are strongly affected by the interfaces between discs If there are small spaces between adjacent discs, attenuation occurs rapidly because of the inefficiency of the air-to-aluminum interfaces If the discs are firmly in contact with each other, however, the interfaces should have virtually no effect on a compressive shock wave. The possible effect of the interfaces can also be eliminated by using solid attenuating blocks of various thicknesses rather than stacks of attenuating discs.

As outlined previously, stacks of 0.051-in.-thick aluminum discs were employed for these experiments. To investigate the effect of interfaces in the stack of discs, a few experiments were also performed using 0.102-in.-thick aluminum discs, which reduced the number of interfaces in a given attenuator thickness by half. A few tests were also performed using solid cylinders of explosive as attenuators. As expected, the 50% thickness was least for the 0.051-in. discs, and greatest for the solid cylinders. The overall curves of 50% thickness vs temperature were, however, of the same general shape for all cases.

5. DROP-IMPACT TEST

The drop-impact test consists of dropping a 2-kg weight onto a 25-mg explosive sample and measuring the drop heights from which the probability of an explosion is 50%. This is one of the most widely used tests for screening explosives to determine their order of sensitivity. It is so often preferred because it may be performed quickly and requires only a small quantity of explosive. The exact nature of what is measured by the test, however, is rather indefinite. It is doubtful that initiation to detonation occurs, because the mass of explosive

is so small. Initiation as a result of rapid shearing or rupture of the explosive molecule has been considered a possible mechanism. More plausibly, explosions by impact may be caused by hot spots formed by adiabatic compression of bubbles in the explosive. If the impact-induced temperature of these spots is of sufficient magnitude, decomposition occurs at an accelerating rate until rapid deflagration results.

5.1 APPARATUS DESIGN

The drop-impact machine used for this program is shown in Figure 11. It is designed similarly to the Picatinny Arsenal machine with modifications to permit heating of the explosive samples. A schematic of the heating modification is shown in Figure 12. The impact tools are shown in Figures 13 and 14. The aluminum seal is employed to prevent the explosive sample from escaping around the plunger during impact.

These impact tools were chosen because they permit the testing of both solid and liquid explosives. A flat impact surface provides inadequate confinement for explosive samples and permits liquid or waxy explosives to escape the impact surfaces more readily than gritty or granular explosives. The use of the cup and aluminum seal provides adequate confinement for all samples and minimizes the effect of the viscosity of the explosive.

When using these impact tools, the spread in sensitivity between the most and least sensitive explosives, and the spread between the 0% and 100% detonation points, was found to be less than when the samples are tested without confinement.

5.2 TEST PROCEDURE

The explosive samples were prepared by screening them through a No. 20 sieve, drying them in an oven at 140°F for 16 hr, and then storing them in a desiccator. The cup and plunger, matched for close tolerance, were inserted into the base and heated to the test temperature. One plunger had a hole drilled through the center to permit insertion of a thermocouple for periodic temperature monitoring. The explosive sample was placed in the cup and an aluminum seal was inserted. A 1-in. seal drop was employed to ensure good contact with the explosive. The sample

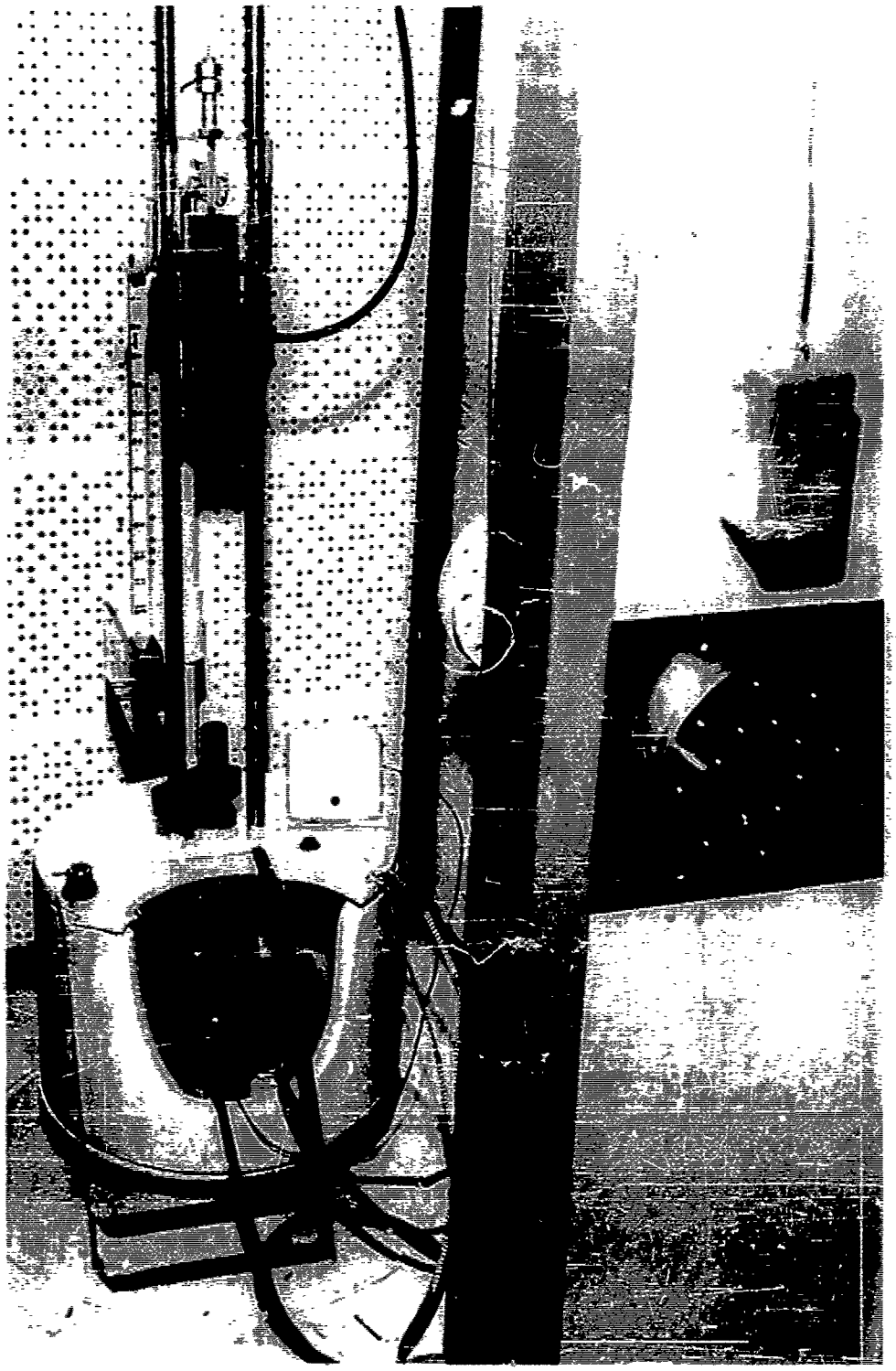


Figure 11. Drop-Impact Machine

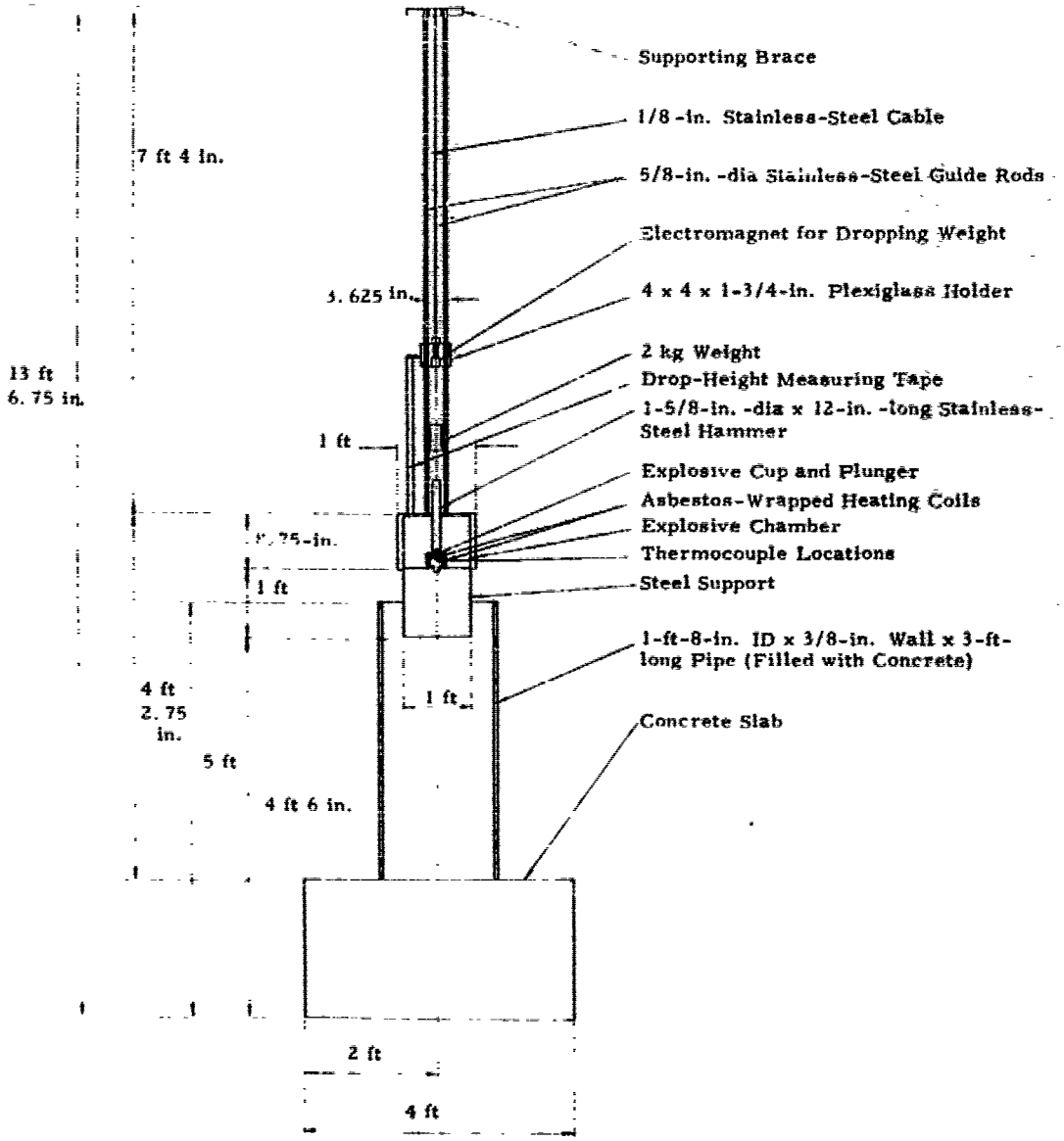
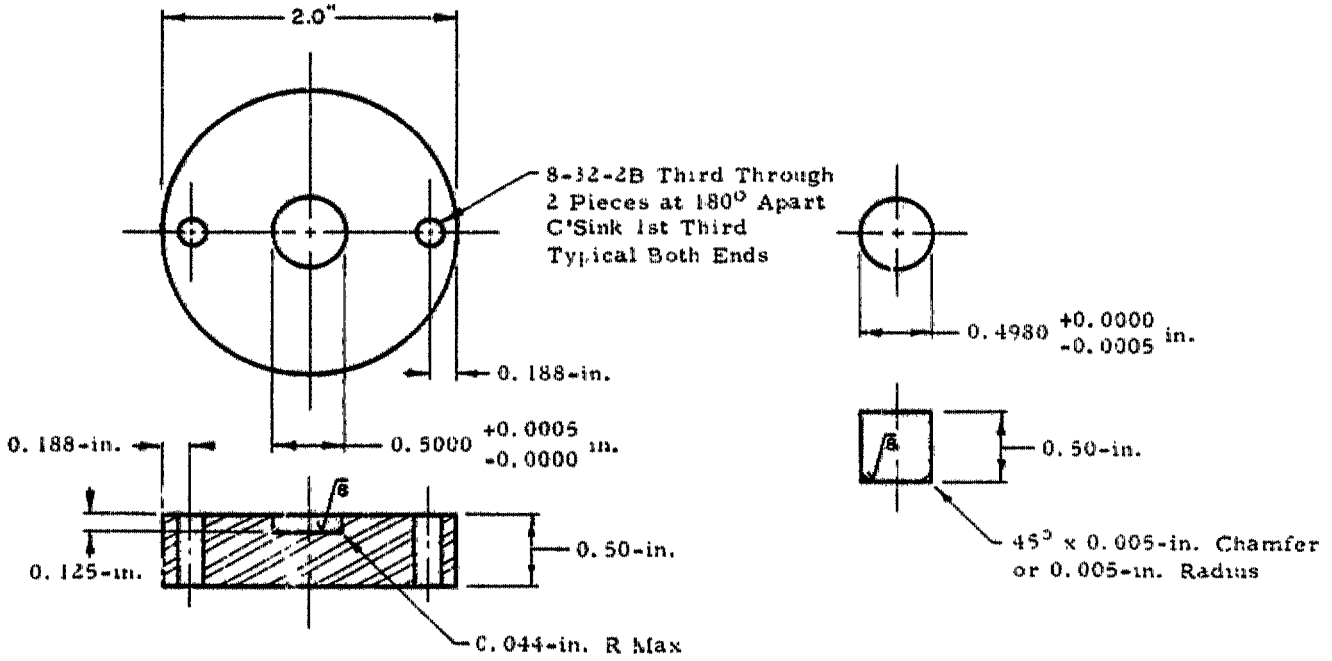


Figure 12. Modified Drop-Impact Machine.

Figure 13. Impact Tools (a).



Finish 32 Except when Otherwise Indicated

Figure 14. Impact Tools (b).

was allowed 30 sec to attain test temperature before the 2-kg weight was dropped. Twenty tests were made at each temperature, using the Bruceton up-and-down method. An analysis of this method has been made by the Statistical Research Group at the Applied Mathematics Panel (Reference 4).

The tests were conducted as follows: The 2-kg weight was set at a height where an explosion was expected and then dropped. An explosion was determined to have occurred if a report was heard, if smoke was observed, if an odor of explosive gases was detected, or if the samples showed any signs of partial decomposition after impact. If initiation occurs, the weight is lowered and the test is repeated. If initiation does not occur, the weight is raised and the test is repeated. This procedure is continued until a point is reached where at a height, X, an explosion occurs, while at a height, X-1, an explosion does not occur. This point now becomes the first test and 20 more tests are conducted, with the weight raised or lowered in c.en increments, depending on the explosive reaction or lack of reaction. The percentage of explosions in the total number of trials at a given height is determined for each height. This percentage is then plotted against the height of the fall and the 50% point is read from the curve. In Figure 15, the connecting lines show the actual test results, with the solid dot, • , indicating initiation and the hollow circle, o, indicating no reaction. The chart is then completed by assigning • values up to a maximum height above each positive trial, and o values down to the lowest negative below each negative trial. It is assumed that if a positive result occurs at X, then X + 1, X + 2, X + 3, etc., will also yield positive results; while if X is negative, then X-1, X-2, X-3, etc., would also be negative.

6. BULLET SENSITIVITY TEST

Bullet sensitivity tests are almost entirely empirical. These tests, however, are considered valuable in increasing the level of confidence in the safety of heated explosives, since a combination of initiation mechanisms may be present. The bullet test has some relationship to operational conditions, since when the bullet penetrates a metal casing and impinges upon the explosive, large frictional and crushing forces are involved which are at least qualitatively similar to the action occurring when a warhead is accidentally dropped or involved in an airplane crash. The test is specifically pertinent, of course, in determining vulnerability of a weapon to fragment impact.

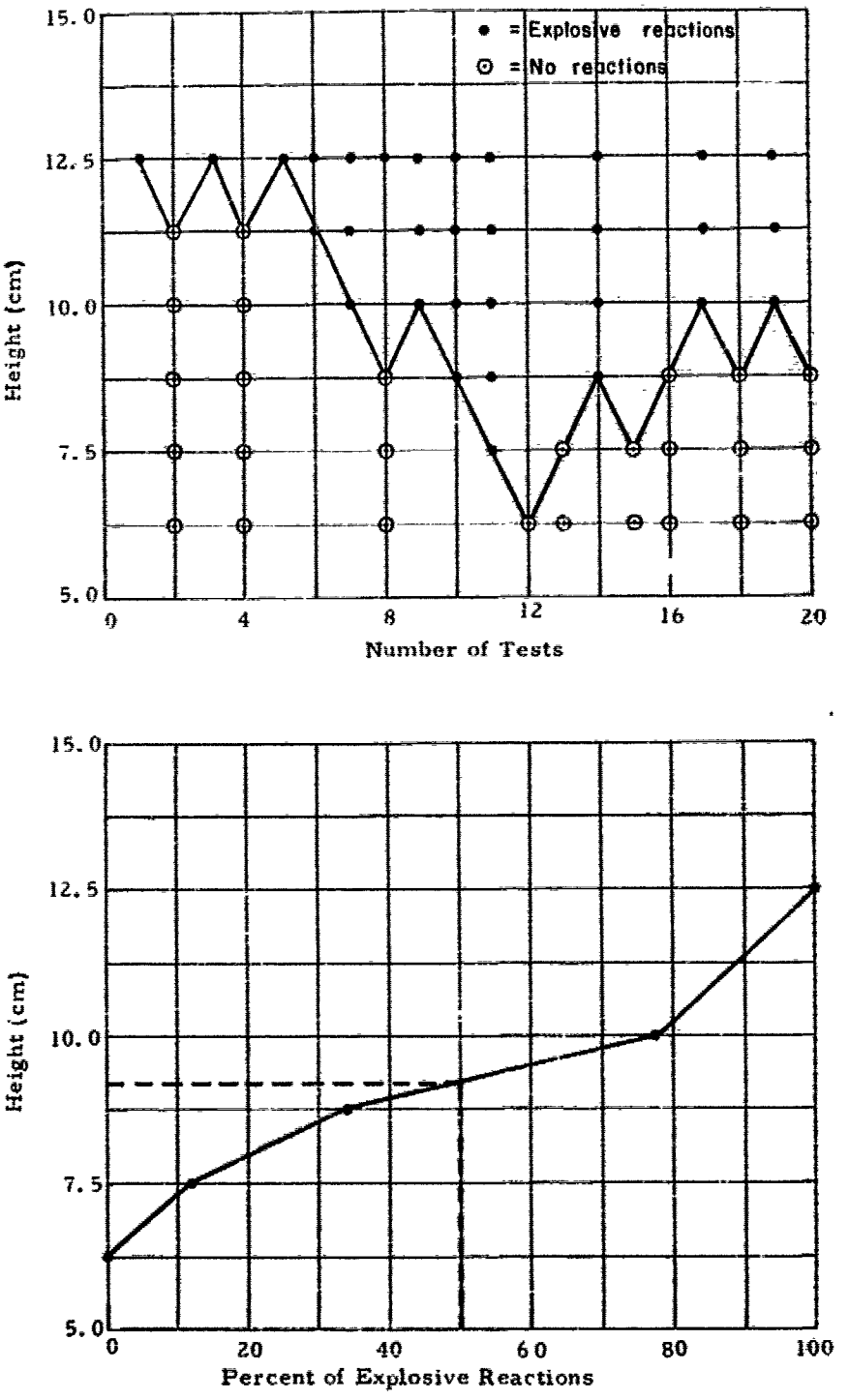


Figure 15. Explosive Reactions in Drop-Impact Testing.

6.1 TEST DESIGN

Several possible parameters exist in the design of bullet-impact sensitivity tests; i e., target-plate thickness and material; bullet velocity, shape, material and mass; and explosive-column length, diameter, and confinement. The proper selection of design parameters must be made so that meaningful data is obtained by which to compare the sensitivity of different explosives at various temperatures. The approximate quantitative effect of the test parameter upon apparent sensitivity must therefore be known.

For the tests conducted as part of this program, bullet velocity was chosen as providing the best measure of sensitivity because this factor can readily be changed by varying the propellant weight. To assure that a change in bullet velocity will be meaningful, however, it must be possible to vary the velocity throughout a range at which the maximum will yield some detonations under the least sensitive conditions while the minimum will fail to cause a reaction in some cases under the most sensitive conditions. Considerable effort was spent to determine test parameters which would yield such results.

There were two variables for each explosive tested: temperature, and bullet velocity. In comparing the sensitivity of two different explosives at the same temperature, the only variable was bullet velocity Therefore, it was possible to determine which explosive was more sensitive by comparing the bullet velocities necessary to cause initiation of each explosive.

The shock-sensitivity arena shown in Figure 4 was modified for the bullet-sensitivity tests (Figure 16). The explosive-heating apparatus was the same as that for the shock sensitivity tests A 30-cal Springfield rifle was mounted in a housing under the reinforced-concrete test chamber. It was desirable to fire the bullet into the explosive container (Figure 17) from below, thus eliminating the possible effect of air spaces and bubbles which might be present at the top or sides of the liquid-explosive column

The rifle was loaded through a port under the test chamber after the explosive had been secured in place. The rifle was fired remotely and a solenoid-operated trap door (for protection of the rifle) was actuated simultaneously with the rifle firing Distance from the rifle muzzle to the explosive was 50 in.

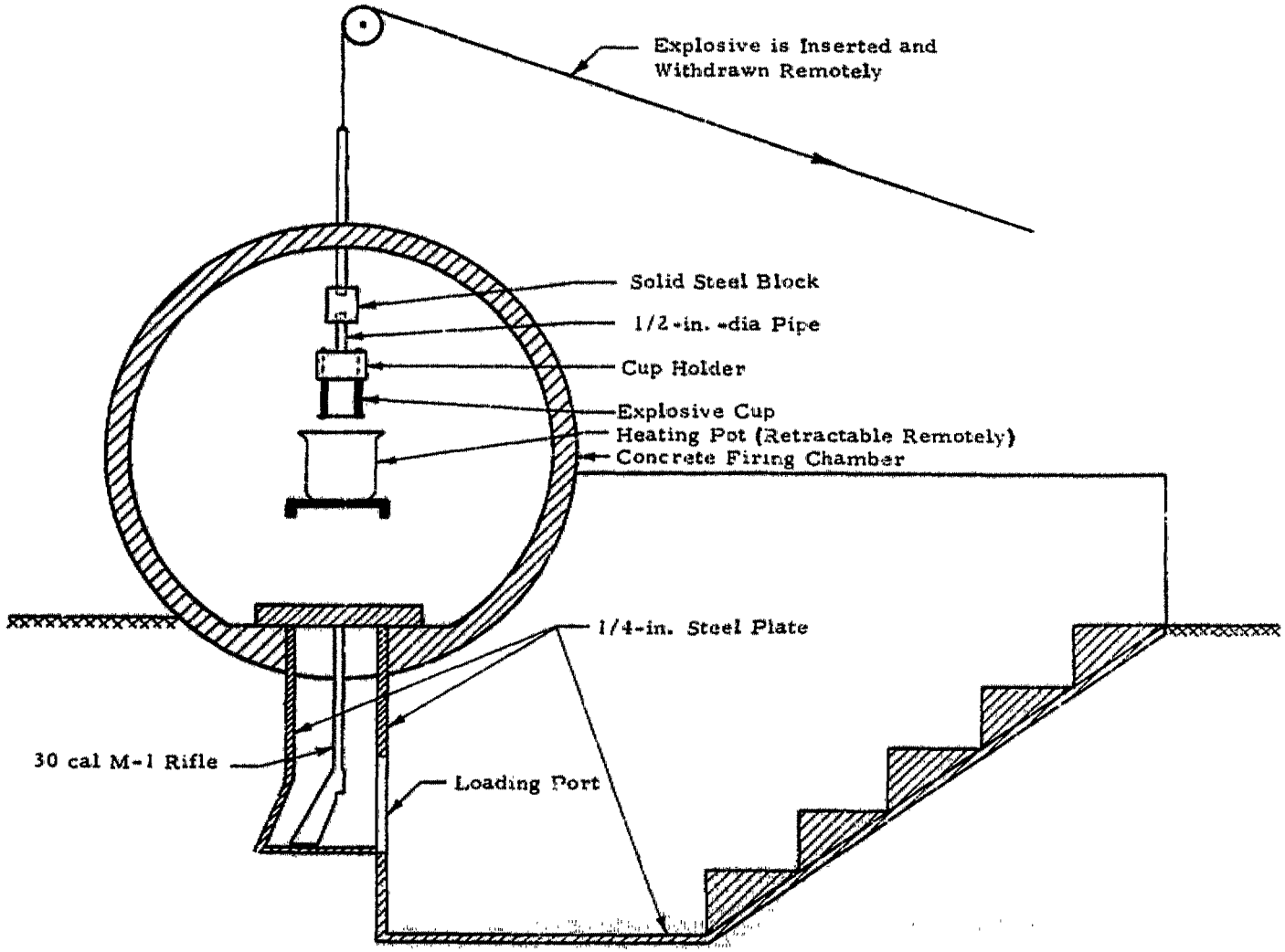


Figure 16. Bullet Sensitivity Test.

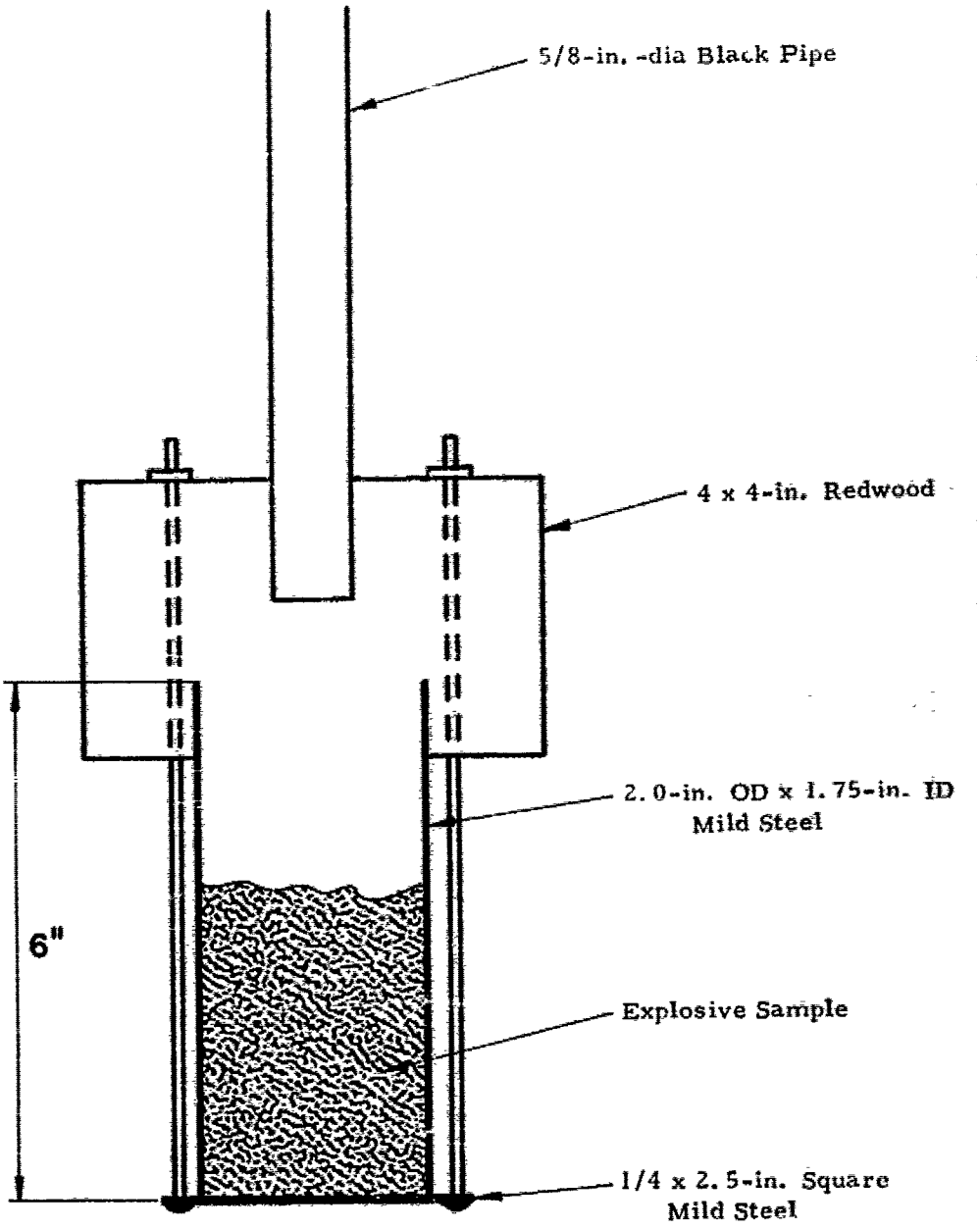


Figure 17. Bullet-Sensitivity Explosive Container.

6.2 TEST DESCRIPTION

The results of the tests were described as follows, in terms of how violent a reaction was initiated in the explosive:

a. No reaction - no visible or audible indication of explosive reaction.

b Partial burning - visible fumes or vapor.

c. Complete burning - visible fumes, with no explosive remaining.

d. Partial detonation - audible sound accompanied by smoke, large fragments, or cracks in the explosive container.

e. Complete detonation - a loud report, with visible smoke sufficient to cause extensive fragmentation of container, and with no evidence of explosive remaining.

7. DETONATION-VELOCITY MEASUREMENT

Detonation velocities can be measured using pin switches, or ionization gaps inserted in the explosive, in which case the shorting of the gap when the detonation wave passes is monitored by an oscilloscope. These velocities can also be measured using a streak camera, which was the technique employed for this program. The photographic method has the advantage of providing a continuous record of the detonation process, including changes in velocity and also the points where fluctuations occur.

7.1 EXPLOSIVE TRAIN AND HEATING ARRANGEMENT

For detonation-velocity measurements with the streak camera, the explosive column must be bare or be confined in an opaque tube with windows. For this study, the explosive was contained in a Pyrex-glass graduate (Scientific Class Company Catalog No. C-9720), with an ID of 1.21 in., and a wall thickness of 0.0065 in. Fiducial marks were made on the graduate with thin strips of opaque tape. The explosive column was 5 in. long. The firing train consisted of a DuPont X-98 arc detonator, a 3/4-in.-diameter x 3/4-in.-high tetryl pellet, and the explosive sample column. Since gas is evolved in the explosive column at higher temperatures, the firing train was arranged vertically, with the detonator on the bottom, and with the top of the explosive column open.

The graduate cylinder was separated from the tetryl pellet by a 2-in.-diameter x 1/4-in.-thick asbestos insulator disk The booster and detonator were shielded by a heavy steel housing so that light from their detonation did not interfere with the velocity trace from the explosive being studied.

A removable heating oven was fitted over the explosive column as shown in Figure 18. This consisted of an aluminum tube wrapped with asbestos and nichrome wire for resistance heating. The explosive test sample was heated to the test temperature in approximately 45 min. The temperature was monitored by thermocouples in the explosive, which were removed along with the oven before the explosive was fired. The rotating mirror of the streak camera was brought to the desired speed, the heating oven was remotely raised from the explosive sample, and the detonator was fired.

7.2 ACCURACY

The luminescence in the detonation wave produces a streak as the image of the explosive charge is swept across the film. Figure 19 shows schematically the type of data which is obtained.

Accuracy of the results depends upon the precision of time and distance measurements, according to the relation

$$\frac{\Delta V}{V} = \frac{\Delta A}{S} + \frac{\Delta t}{t}$$

where ΔV = velocity error

V = velocity (assume V = 25,000 fps)

ΔS = distance error (assume ΔS = 0.01 in.)

S = distance (assume S = 5 in.)

Δt = time error (assume $\Delta t = 20 \times 10^{-9}$ sec)

t = time (assume $t = 16.5 \times 10^{-6}$ sec)

With these nominal assumptions, accuracy is measured to within about 3 parts in 1000.

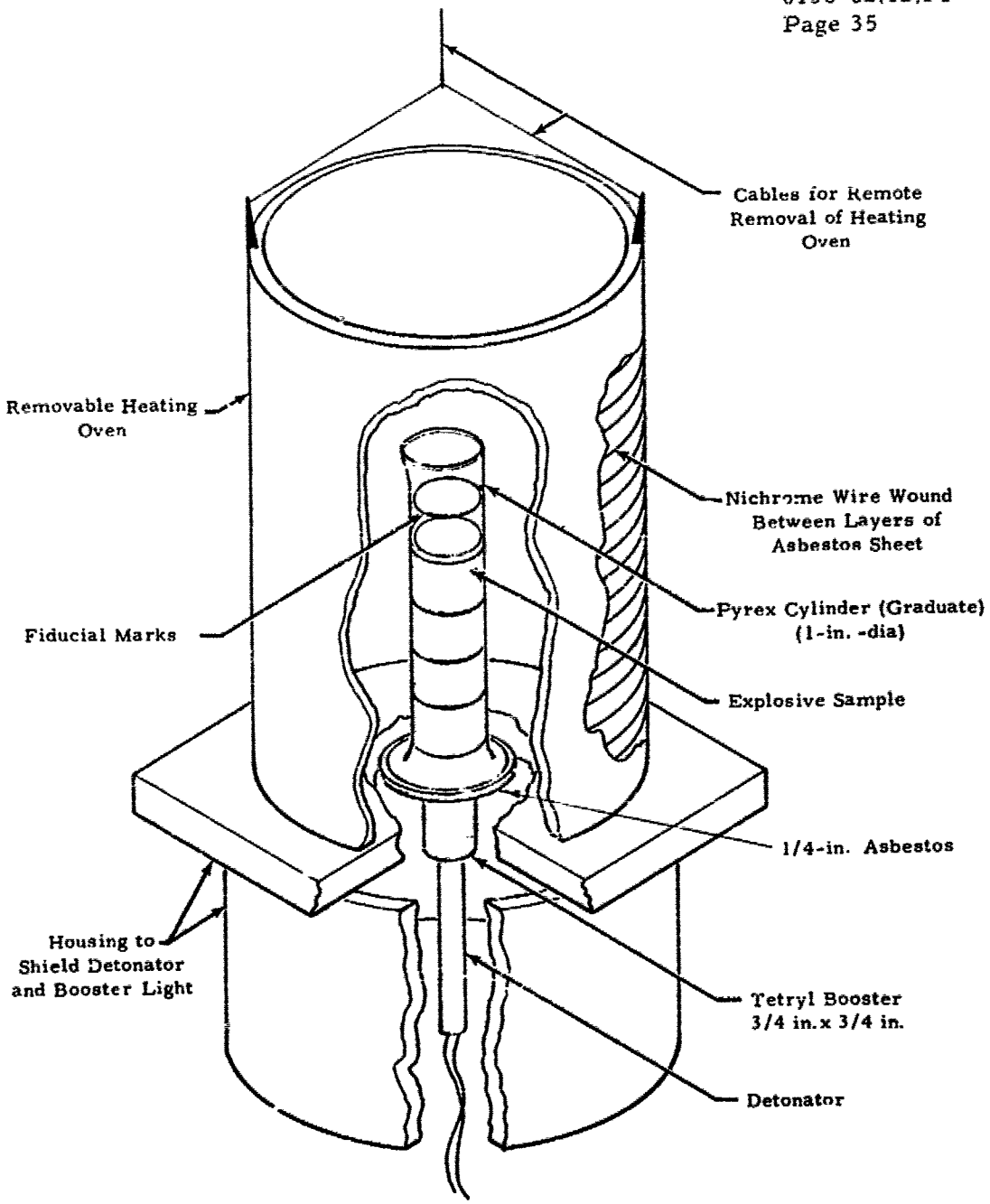


Figure 18. Detonation-Velocity Apparatus.

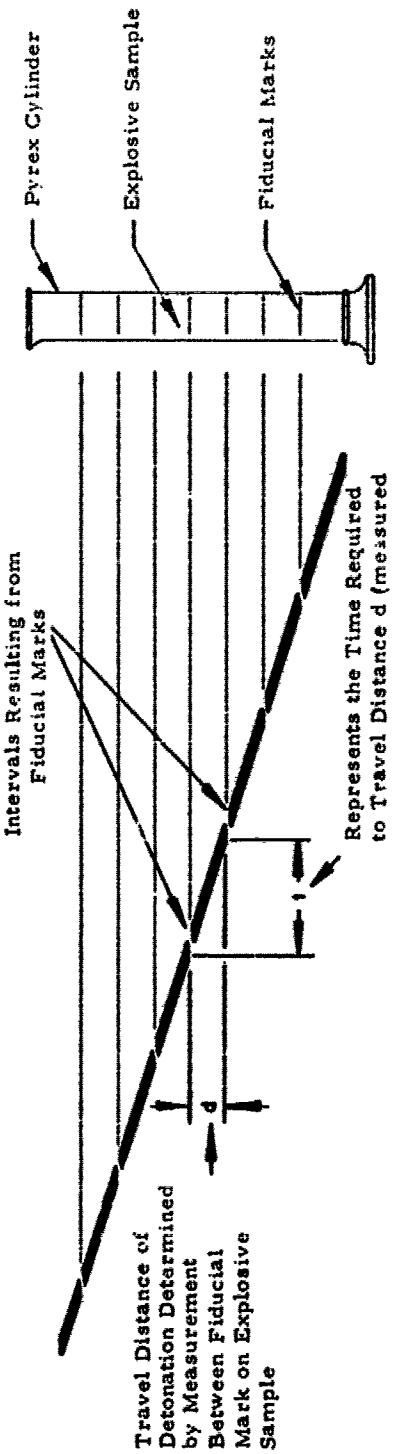


Figure 19. Illustration of Velocity Interpretation from Streak-Camera Record.

8. THERMAL EXPANSION

Thermal expansion can be measured in explosives up to the temperature where gas is evolved during the experiment. However, cracking and stress relieving in some solid explosives may occur well below the point where significant decomposition occurs. For this reason, dilatometric expansion techniques cannot be used. Volumetric displacement was therefore used to measure expansion (Reference 6).

The explosive sample was immersed in a measured quantity of Fluorolube oil in a glass weighing bottle (Ace Glass Company Catalog No. 5566) similar to that used in the large-scale thermal stability apparatus (Section 3). This apparatus is shown in Figure 20. Entrapped air was removed from the oil and explosive by evacuating the system, and then returning it to atmospheric pressure. The weighing bottle was lowered into an oil bath for heating. This bath was slowly heated by the same technique used for the thermal stability tests. Temperature in the explosive, monitored by thermocouple, was allowed to come to equilibrium with the oil bath at intervals of about $30^{\circ}F$. At these points, the rise of Fluorolube in the calibrated stem of the container was measured.

The container and Fluorolube were calibrated by following the previously described procedure without a specimen. The stem itself was calibrated volumetrically by measuring the change in length occupied by the addition of a known quantity of liquid.

The coefficient of volumetric expansion was calculated by use of

$$\alpha = \frac{1}{V_1} \quad \frac{V_2 - V_1}{T_2 - T_1}$$

α = coefficient of volumetric expansion

V_1 = volume at temperature T_1

V_2 = volume at temperature T_2

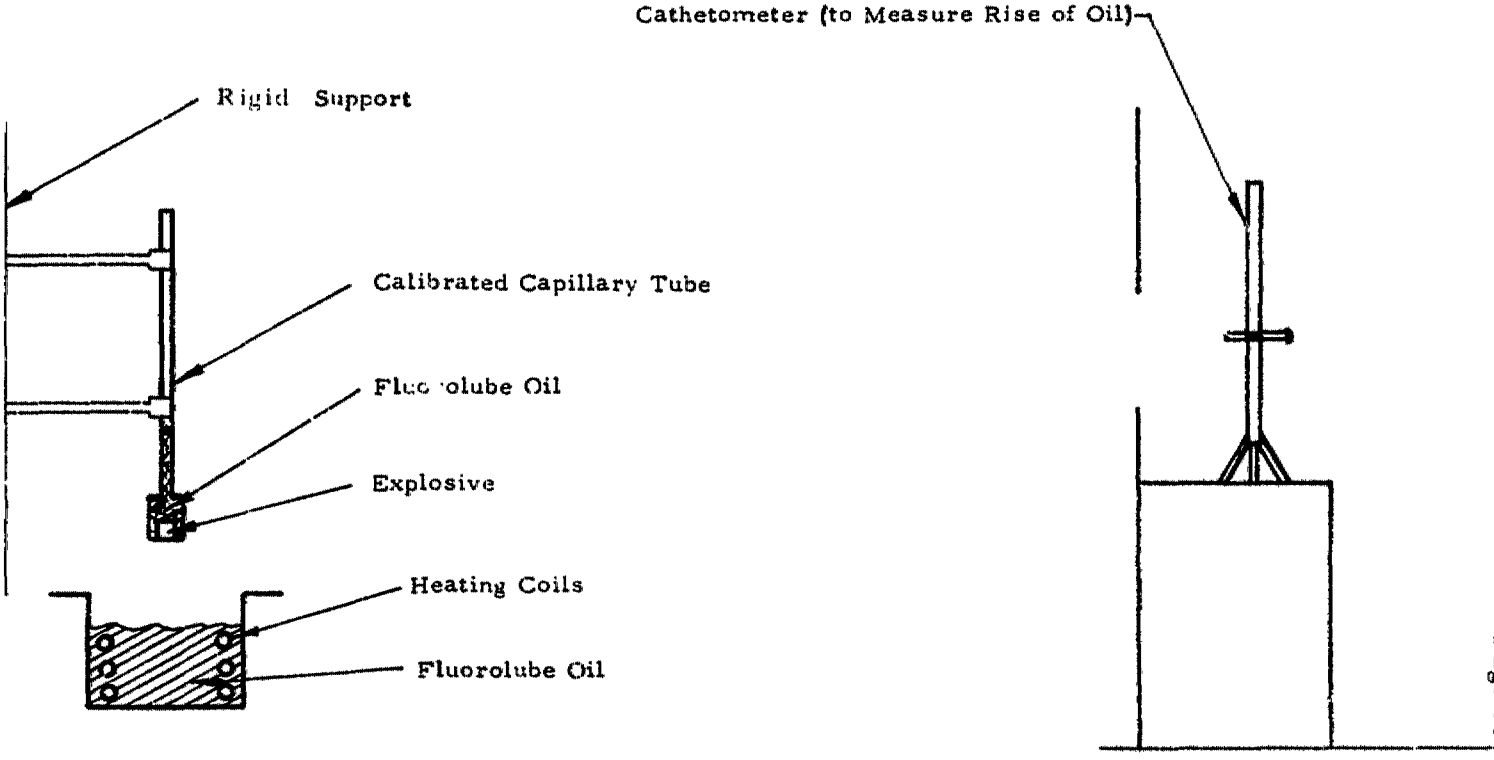


Figure 20. Thermal Expansion Apparatus.

Knowing the coefficient of volumetric expansion for the Fluorolube and container used (a_o) and $\frac{V_2 - V_1}{T_2 - T_1}$ for the system with the explosive specimen, the calculation of a for the specimen was

$$\frac{\frac{V_2 - V_1}{T_2 - T_1} - a_o V_{Fluorolube}}{V_{explosive}} = a \text{ explosive}$$

9. THERMAL DIFFUSIVITY

This test series was intended to study diameter-time-temperature relationships during the flow of heat into cylinders of nonmelting explosives when the explosives were exposed to high temperatures. Excessive cracking and swelling of the samples tested forced abandonment of these objectives. However, since the heating-bath apparatus had already been built, it was believed that useful information on thermal diffusivity and conductivity could be obtained with a minimum of effort.

Thermal diffusivity is the quantity of heat passing through a unit area per unit time, divided by the product of specific heat and the temperature gradient. This quantity determines the rate at which a body with nonuniform temperature approaches equilibruim.

An approximate method for the calculation of thermal diffusivity was used. This method was devised for an inert cylindrical sample with heat flowing radially (References 7, 8, and 9). For a finite cylinder having a length at least four times its radius, the equation is

$$K = \frac{a^2}{5.78\, t} \left[\frac{-\ell n\, T_t}{T_{t=0}} + 0.47\, 1 \right]$$

K = thermal diffusivity (cm^2/sec)

a = radius of cylinder (cm)

t = time (sec)

T_t = difference between surface and center temperature

$T_{t=0}$ = T_t at zero time

9.1 DESCRIPTION OF APPARATUS

The test setup consisted of a heating tank, cold-oil tank, and the explosive-heating container. Regal type PC oil (flash point about 370°F) was used as the heating medium. The oil was heated by three immersion-tube-type heaters (Braun Chemical Company Catalog No. 33890, quick action with copper sheath) the power input of which was controlled by a 1-kw variable resistor. The oil was circulated from the 25-gal oil-heating tank through the explosive test chamber at a rate of 5 gpm. Both the oil-heating tank and the explosive-heating container were wrapped with a 4-in. layer of Ultralite insulation. The 50-gal cold-oil tank was remotely operated by means of solenoid valves. The system could be flushed with cold oil to avoid undesirable explosions by slowing down any rapidly accelerating reaction which might develop in the explosive.

Test samples were conditioned in a 100°F preheat bath before being remotely placed into the test bath which had been preheated to the test temperature. Fluorolube FS-5 was used in both the preheat bath and the explosive test chamber (Figures 21 and 22).

The explosive samples consisted of pressed PBX N-1 and PBX N-3 cylinders 2 and 5 in. in diameter by 3 in. long. Each test charge was formed by bonding together two such cylinders with Sauereisen No. 1 Cement (Braun Chemical Company Catalogue No. 19975). Thermocouples were inserted 2.75 in. into the top cylinders and the holes were closed by coating the thermocouple wire with Sauereisencement before insertion. Continuous temperature-time measurements were made using a continuous-writing multipoint temperature recorder.

9.2 ACCURACY

Temperature control of the test bath provided the major error in this experiment. Although circulation in this test bath amounted to 5 gal of oil per minute, a drop of approximately 20°F was observed when samples were placed into the bath. This temperature drop was eliminated quickly, but in varying time intervals for each test. Therefore, to ensure steady temperature flow into the samples, the first calculations in each test were made after 720 sec. Deviation from linearity is apparent in test curves below this point.

An increase in heat flow was also observed after 3000 sec. This possibly could have resulted from the severe cracking observed. Data were not taken after these deviations occurred.

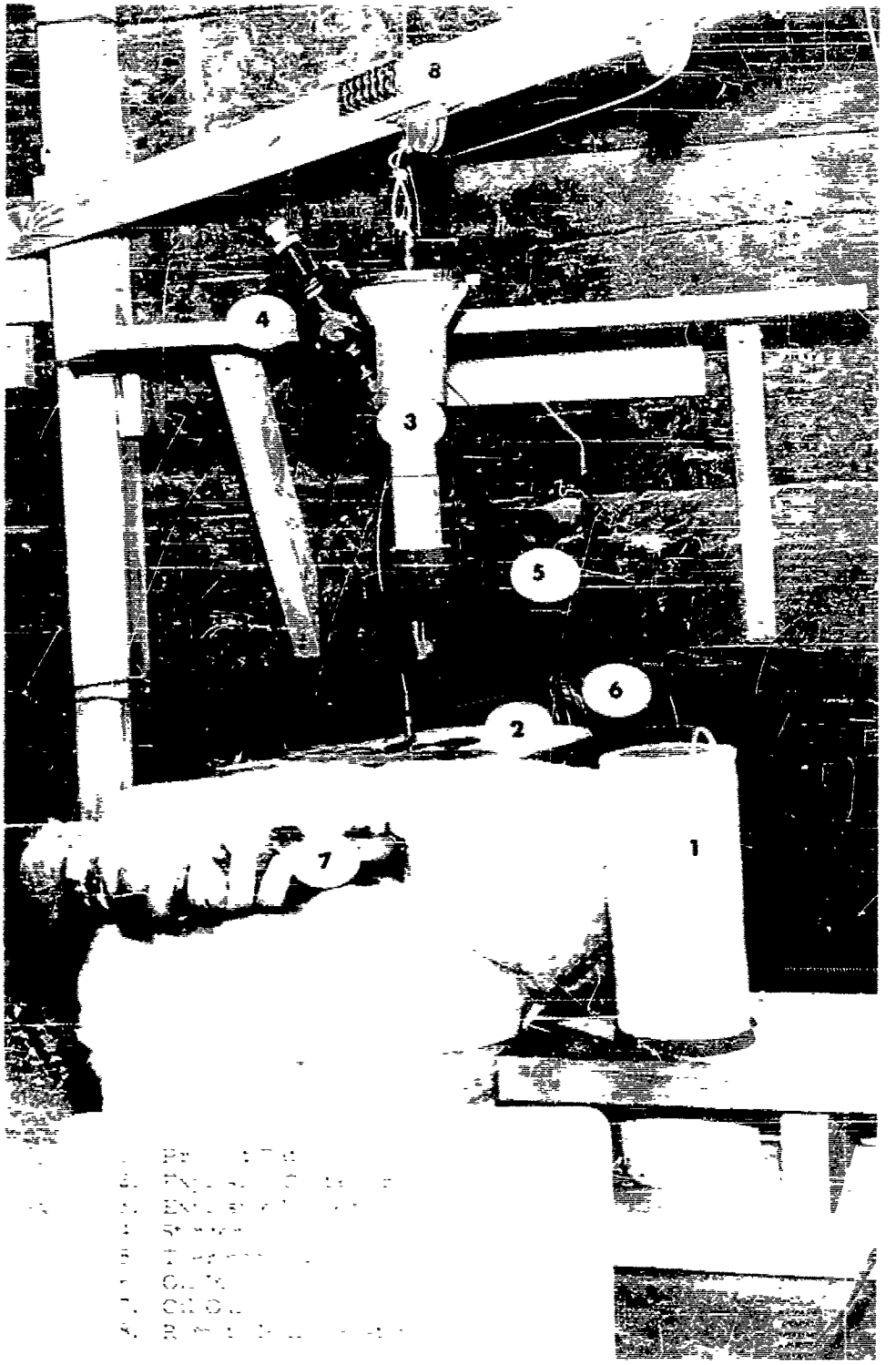


Figure 2. Test Setup for Thermal Diffusivity Tests (a).

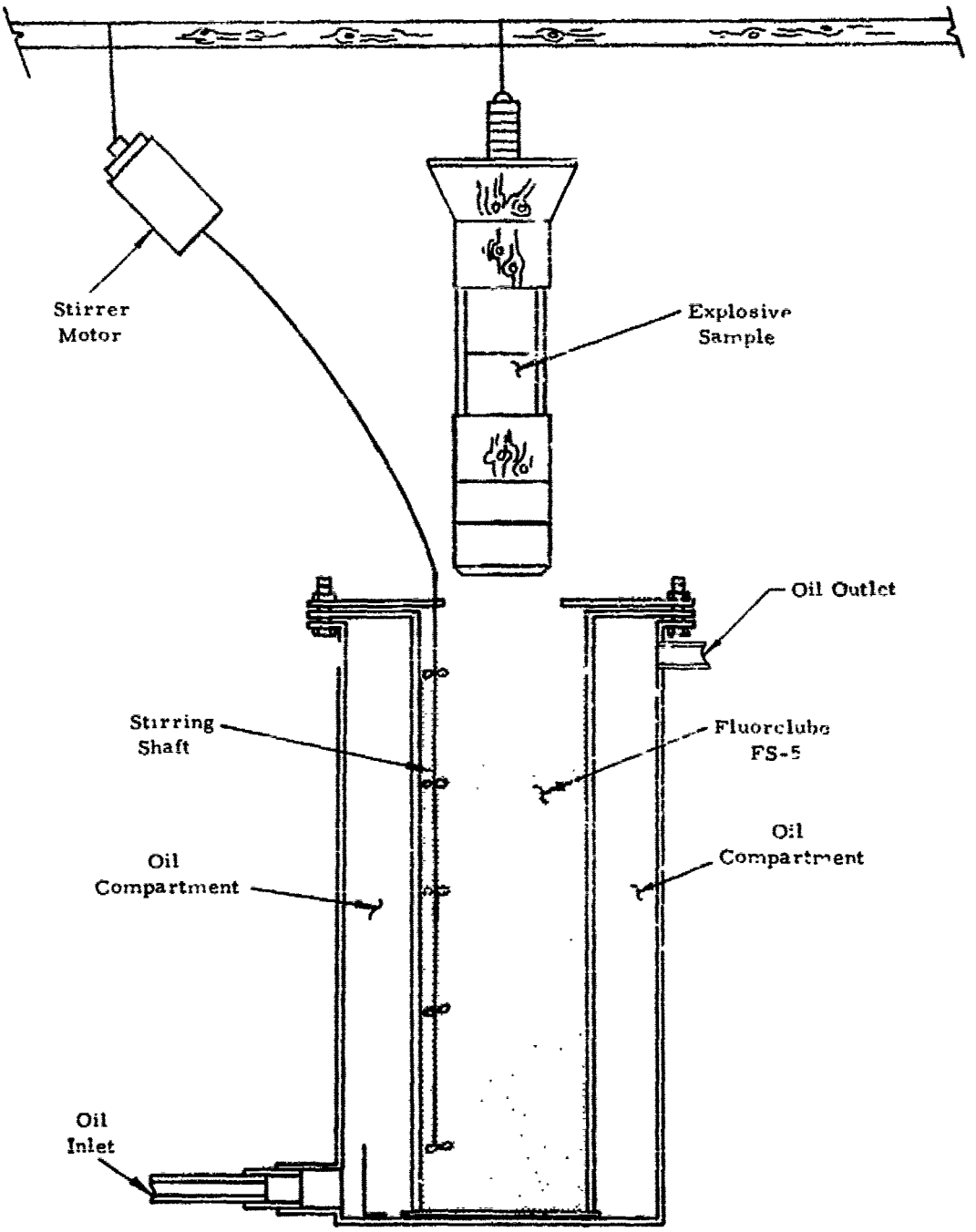


Figure 22. Test Setup for Thermal Diffusivity Tests (b).

1554-10-8-1

REFERENCES

1. Taliani Apparatus for the Measurements of the Thermal Stability of Explosives, NOLM 10288, Naval Ordnance Laboratory, White Oak, Maryland (CONFIDENTIAL).

2. R. Pope and E. G. Whithead, Sensitivity of Solid and Liquid Explosives, Part 3. "The application of the Cap Test to Liquid Explosive," Ministry of Supply, Explosive Research and Development Establishment Technical Memo No. 21/M/52, March 1953 (CONFIDENTIAL).

3. Detonability of Solid Propellants -- Test Methods and Instrumentations, U. S Naval Ordnance Laboratory Report No. 5788, Februarv 1958 (UNCLASSIFIED)

4 Statistical Analysis for a New Procedure in Sensitivity Experiments. Applied Mathematics Panel Report No. 101-1R, July 1944, SRC - P No. 40.

5. Development of an Improved Rifle-Bullet Impact-Sensitivity Test, Picatinny Arsenal Report No. 2247. May 1958 (UNCLASSIFIED)

6. A. Sauer, et al. Journal of Applied Physics, Vol. 30, 1959, pp. 1988 et seq.

7. M. Jakot, Heat Transfer, John Wiley & Sons, 1949.

8. H. S. Carslaw, Conduction of Heat in Solids. Clarendon Press, Oxford, 1959.

9. L. Shulman, Thermal Diffusivity of HBX-3, General Laboratory Report, Picatinny Arsenal, 1955 (CONFIDENTIAL).

DISTRIBUTION

Chief, Bureau of Naval Weapons
Department of the Navy
Washington 25. D C.
Attn: RUME 2
RMMO 2
RRRE 1

INSORD/Azusa 1

Commanding Officer
Naval Mine Depot
Yorktown, Virginia
Attn: R and D Division 1

Commanding Officer
Picatinny Arsenal
Dover, New Jersey 2

Commanding Officer
Picatinny Arsenal
Dover, New Jersey
Attn: Dr. H. J. Matsugma 1
Dr. J. V.R Kaufman 1
S. J. Lowell 1

Commander
Naval Proving Ground
Dahlgren, Virginia 1

Commander
Naval Ordnance Test Station
China Lake, California
Attn: Technical Library 1
Code 454 1
Kit Skaar 1
Code 753 2

Superintendent
U S Naval Postgraduate School
Monterey, California (ONR) 1

Chief of Naval Operations
Department of the Navy
Washington 25, D. C.
Attn: Op-374 (OEG) 1

Chief of Naval Research
Department of the Navy
Bldg. T-3,
Washington, D. C. 1

Commanding Officer
Nuclear Weapons Training Center
Atlantic Naval Base,
Norfolk 11, Virginia
Attn: Nuclear Warfare Dept. 1

Commanding Officer
Fleet Training Center
(SPWP School)
Naval Station
San Diego 36, California 1

Chief, AFSWP
Box 2610. Pentagon
Washington, D. C 1

Armed Services Technical
Information Agency
Arlington Hall Station
Arlington 12 Virginia 10

Commander
Air Materiel Command
Wright Patterson Air Force Base
Dayton, Ohio
Attn: MCAIDS 1

Director
U.S Naval Research Laboratory
Washington 25. D C. 1

DISTRIBUTION (Continued)

Commanding Officer and Director
U. S Naval Engineering
Experiment Station
Annapolis, Maryland 1

Commanding Officer,
Naval Propellant Plant
Indian Head, Maryland
Attn: EODTC 1

Chief of Naval Operations
Department of the Navy
Washington 25, D C 1

Assistant Secretary of Defense
Research and Engineering
Department of Defense
Washington 25, D. C.
Attn: Technical Library 1

Chief of Ordnance
Department of the Army Research
and Development Division
Washington 25, D. C.
Attn: ORDTQ 1

Chief Chemical Officer
Department of the Army
Washington 25, D. C. 1

Commanding General
Aberdeen Proving
Ground, Maryland
Attn: Director, Ballistic
Research Laboratories 3

Director
National Bureau of Standards
Washington, D. C.
Attn: Security Officer 1

Commander,
Air Force Systems Command
P. O. Box 1395
Baltimore 3, Maryland
Attn: RDDN 1

Commander,
Air Proving Ground Center
Eglin Air Force Base, Florida
Attn: Technical Reports Branch 1

Commander,
Aeronautical Systems Division
Wright-Patterson Air Force Base
Dayton, Ohio
Attn: WCEGH-3 1

Director
Weapons System Evaluation Group
Office of the Secretary of Defense
Room 2E1006
Pentagon, Washington 25, D. C 1

Chairman, Armed Service
Explosives Safety Board
Department of Defense
Room 2403, Barton Hall
Washington 25, D C. 1

Institute for Air Weapons Research
University of Chicago
Chicago, Illinois
(AF33(616)-3274) 1

Director
Los Alamos Scientific Laboratory
P. O. Box 1663
Los Alamos, New Mexico
Attn: D. P. MacDougall 1

DISTRIBUTION (Continued)

Commanding Officer
Engineer Research and
Development Laboratory
Fort Belvoir, Virginia 1

Director
Division of Military Application
U. S. Atomic Energy Commision
Washington 25, D. C.
Attn: Dr. Paul Fine 1

Director, Division of Research
U. S. Atomic Energy Commission
Washington 25, D. C 1

Technical Library
Army Chemical Center, Maryland 1

Commander, Ooama
Attn: OOR Air Force Ammunition
Services Office
Hill Air Force Base, Utah 1

Denver Research Institute
University of Denver
(Contract NOrd 16009)
Denver 10, Colorado 1

University of California
Lawrence Radiation Laboratory
Livermore, California
Via: Technical Information
Division 1

Director
Operations Research Office
Johns Hopkins University
7100 Connecticut Avenue
Chevy Chase, Maryland 1

University of Utah
Salt Lake City. Utah
Attn: Dr Melvin Cook
(C-NOrd 17371) 1

Director
Applied Physics Division
Sandia Corporation
Albuquerque, New Mexico 1

Librarian of Documents
Armour Research Foundation
Technology Center
Chicago 16. Illinois
Attn: Miss Mary Lee Patterson 1

National Northern Corporation
West Hanover, Mass. 1

Commander
Naval Ordnance Laboratory
White Oak, Maryland
Attn: Library 1
K. W. Division 1
Dr. A. D. Solem 1

Stanford Research Institute
Menlo Park, Calif.
Via. Contracting Officer
SF Ordnance Dist.
U. S. Army
P. O. Box 1829
1515 Clay Street
Oakland 12. Calif. 1

Commander
U.S.A.F. Special Weapons Center
Kirtland Air Force Base
Albuquerque, New Mexico 1

DISTRIBUTION (Continued)

U. S Naval Nuclear Ordnance
Evaluation Unit,
Kirtland Air Force Base
Albuquerque, New Mexico
Attn: W Gordon, Head,
Thermal Radiation and
Fire Division 1

Weapons Laboratory
Detachment 4, ASD
Eglin AFB, Florida
Attn: D M. Davis 1

Applied Physics Laboratory
Johns Hopkins University
Silver Spring, Maryland 1